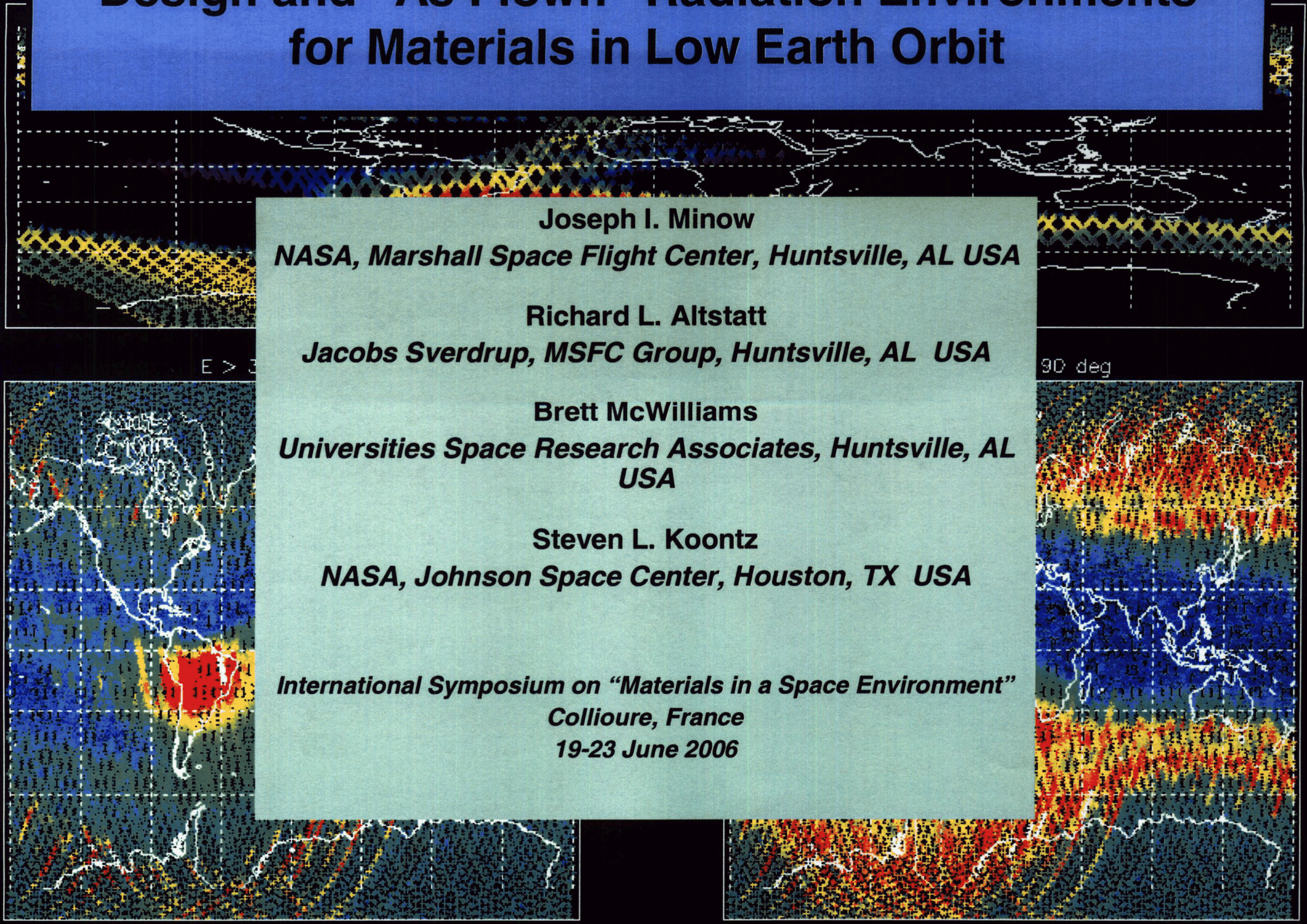
Design and "As Flown" Radiation Environments for Materials in Low Earth Orbit



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International Symposium on "Materials in a Space Environment"
Collioure, France
19-23 June 2006

Overview

- Introduction
  - ISS materials qualified for ~10 years on orbit to design environment
  - Some materials have now been exposed to periods of ~7 years
  - Can they be used longer to save replacement cost, effort?

- ISS Design Environments

- Constructin of “As Flown” reference environment

- Summary

Issue

- SSP 30512 provides a conservative proton, electron environment for use in estimating radiation dose effects on materials

- ISS has been on orbit now for ~5 years
  - How does the "as-flown" environment compare to the (conservative) design environment?
  - How are materials qualified for 10 years holding up?
  - If design environment was conservative, can space exposed materials on exterior of ISS qualified for 10 years be used for longer periods before replacement is required
    - Significant program impact if replacement activities can be reduced (or eliminated)

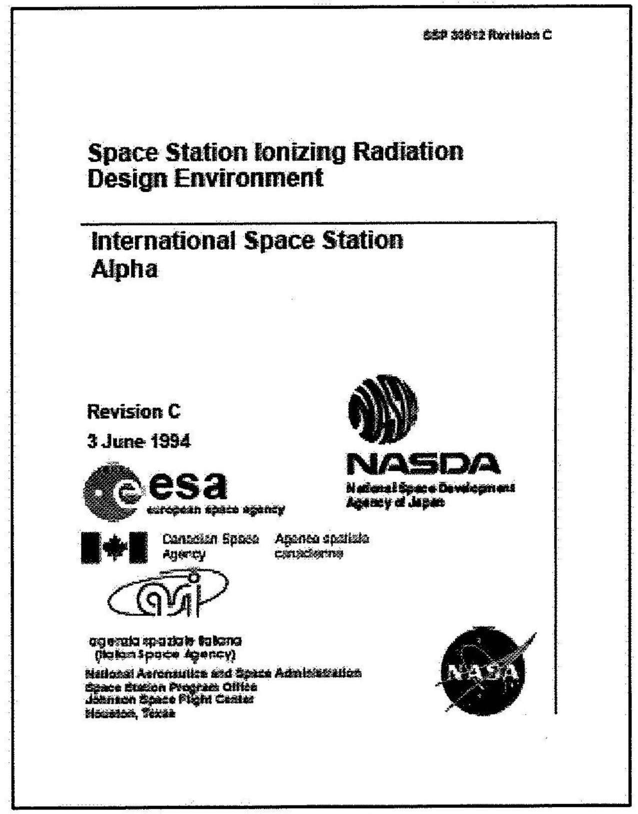
- Add "as-flown" radiation environment to SSP-30512 to supplement the design environment for studies of on-orbit performance of materials

30512 Design Environment

SSP-30512 Revision C
"Radiation Environment for Design"

- Electron, proton environments for dose are conservative by design
  - 500 km, 51.6 deg inclination
  - AE-8 max, AP-8 max
  - Recomment 2x dose environment to account for solar particle events, cosmic rays, secondary particles, other sources not included in environment

- Dose in Si as function of depth in Al for:
  - Sphere — electronics, surface coatings
  - Semi-infinite slabs — surface materials


SSP 30512 Revision C

Space Station Ionizing Radiation Design Environment

International Space Station Alpha

Revision C
3 June 1994

esa european space agency
NASDA National Space Development Agency of Japan
Canadian Space Agency / Agence spatiale canadienne
agenzia spaziale italiana (Italian Space Agency)
National Aeronautics and Space Administration
Space Station Program Office
Johnson Space Flight Center
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30512 Design Environment

TABLE 3.1.2-2 ONE YEAR DOSE IN SEMI-INFINITE ALUMINUM MEDIUM (RADS SI) Sheet 1 of 2					
SHIELDING (MILS)	SHIELDING (MM)	SHIELDING (G/CM^2)	ELECTRONS	PROTONS	TOTAL DOSE
3.000E-02	7.620E-04	2.118E-04	3.795E+05	2.904E+04	4.086E+05
8.000E-02	2.032E-03	5.649E-04	3.021E+05	1.209E+04	3.142E+05
1.000E-01	2.540E-03	7.061E-04	2.834E+05	9.044E+03	2.924E+05
		-03	2.490E+05	5.271E+03	2.543E+05
		-03	2.247E+05	3.486E+03	2.282E+05
		-03	1.912E+05	1.921E+03	1.932E+05
		-03	1.682E+05	1.273E+03	1.695E+05
		-03	1.505E+05	9.225E+02	1.514E+05
		-03	1.366E+05	7.147E+02	1.373E+05
		-03	1.250E+05	5.730E+02	1.255E+05
		-03	1.149E+05	4.812E+02	1.154E+05
		-03	1.065E+05	4.107E+02	1.069E+05
		-03	9.232E+04	3.201E+02	9.264E+04
		-03	8.622E+04	2.856E+02	8.650E+04
		-03	8.088E+04	2.626E+02	8.114E+04
		-03	7.608E+04	2.411E+02	7.633E+04
		-02	7.170E+04	2.260E+02	7.192E+04
		-02	6.771E+04	2.133E+02	6.792E+04
		-02	6.400E+04	1.979E+02	6.419E+04
		-02	6.050E+04	1.896E+02	6.069E+04
		-02	5.732E+04	1.806E+02	5.750E+04
		-02	5.445E+04	1.734E+02	5.462E+04
		-02	4.291E+04	1.431E+02	4.305E+04
		-02	3.443E+04	1.253E+02	3.456E+04
		-02	2.834E+04	1.122E+02	2.846E+04
		-02	2.368E+04	1.020E+02	2.378E+04
		-02	1.992E+04	9.422E+01	2.001E+04
		-02	1.708E+04	8.844E+01	1.717E+04
		-02	1.290E+04	7.976E+01	1.298E+04
		-02	9.975E+03	7.312E+01	1.005E+04
		-02	7.997E+03	6.888E+01	8.066E+03
		-02	6.539E+03	6.492E+01	6.604E+03
		-02	5.406E+03	6.190E+01	5.468E+03
		-01	2.634E+03	5.167E+01	2.685E+03
		-01	1.609E+03	4.563E+01	1.655E+03
		-01	1.111E+03	4.180E+01	1.153E+03

TABLE 3.1.1-2 AP8MAX DIFFERENTIAL AND INTEGRAL FLUX ENERGY SPECTRA FOR TRAPPED PROTONS		
Energy (MeV)	Integral Flux (protons/cm^2-day)	Differential Flux (protons/cm^2-day-MeV)
0.01	8.251E+07	5.060E+08
	6.456E+07	3.658E+08
	2.266E+07	9.764E+07
	9.335E+06	2.326E+07
	3.892E+06	4.131E+06
	2.820E+06	1.431E+06
	2.310E+06	6.088E+05
	2.117E+06	3.255E+05
	1.978E+06	2.345E+05
	1.831E+06	1.517E+05
	1.742E+06	9.828E+04
	1.621E+06	6.184E+04
	1.435E+06	2.995E+04
	1.244E+06	1.469E+04
	1.128E+06	1.022E+04
	9.533E+05	8.440E+03
	7.213E+05	6.914E+03
	5.920E+05	6.141E+03
	3.434E+05	3.623E+03
	2.060E+05	2.192E+03
	1.184E+05	1.299E+03
	6.876E+04	7.385E+02
	4.045E+04	4.288E+02
	2.382E+04	2.507E+02
	1.412E+04	1.510E+02
	8.171E+03	8.710E+01
	4.861E+03	5.340E+01
	2.719E+03	3.397E+01
	1.389E+03	2.623E+01
	3.683E+02	9.778E+00

TABLE 3.1.1-1 AE8MAX DIFFERENTIAL AND INTEGRAL FLUX ENERGY SPECTRA FOR TRAPPED ELECTRONS		
Energy (MeV)	Integral Flux (elecrons/cm^2-day)	Differential Flux (electrons/cm^2-day-MeV)
0.01	1.974E+10	1.708E+11
0.04	1.523E+10	1.311E+11
0.07	1.178E+10	1.005E+11
0.10	9.128E+09	8.289E+10
0.20	3.457E+09	3.104E+10
0.30	1.507E+09	1.076E+10
0.50	4.409E+08	1.940E+09
0.70	2.348E+08	6.194E+08
0.90	1.509E+08	3.142E+08
1.00	1.241E+08	2.176E+08
1.10	1.060E+08	1.660E+08
1.20	9.072E+07	1.413E+08
1.30	7.766E+07	1.205E+08
1.40	6.652E+07	1.028E+08
1.50	5.701E+07	8.951E+07
1.60	4.859E+07	7.759E+07
1.70	4.143E+07	6.600E+07
1.80	3.533E+07	5.617E+07
1.90	3.015E+07	4.782E+07
2.00	2.573E+07	4.015E+07
2.50	1.193E+07	2.018E+07
2.75	7.491E+06	1.375E+07
3.00	4.766E+06	8.715E+06
3.25	3.002E+06	5.495E+06
3.50	1.909E+06	3.665E+06
4.00	6.902E+05	1.489E+06
4.50	2.199E+05	5.079E+05
5.00	6.850E+04	1.770E+05
5.40	2.178E+04	6.239E+04

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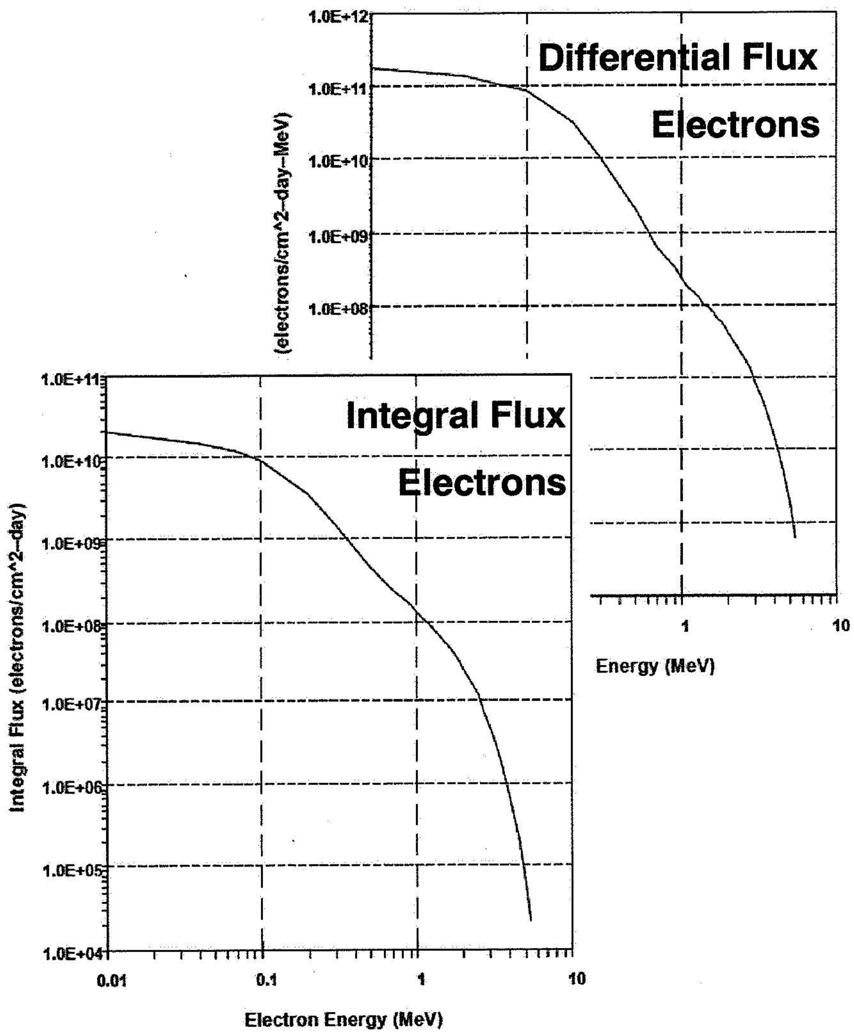
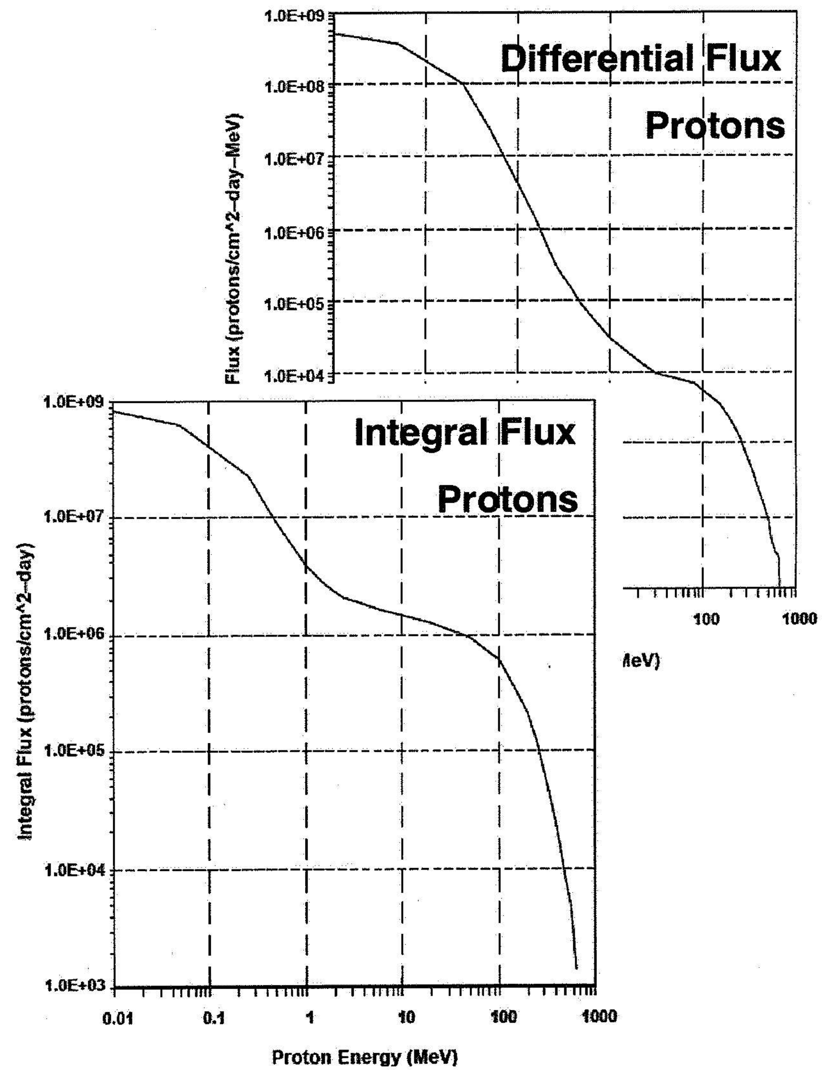
30512 Design Environment





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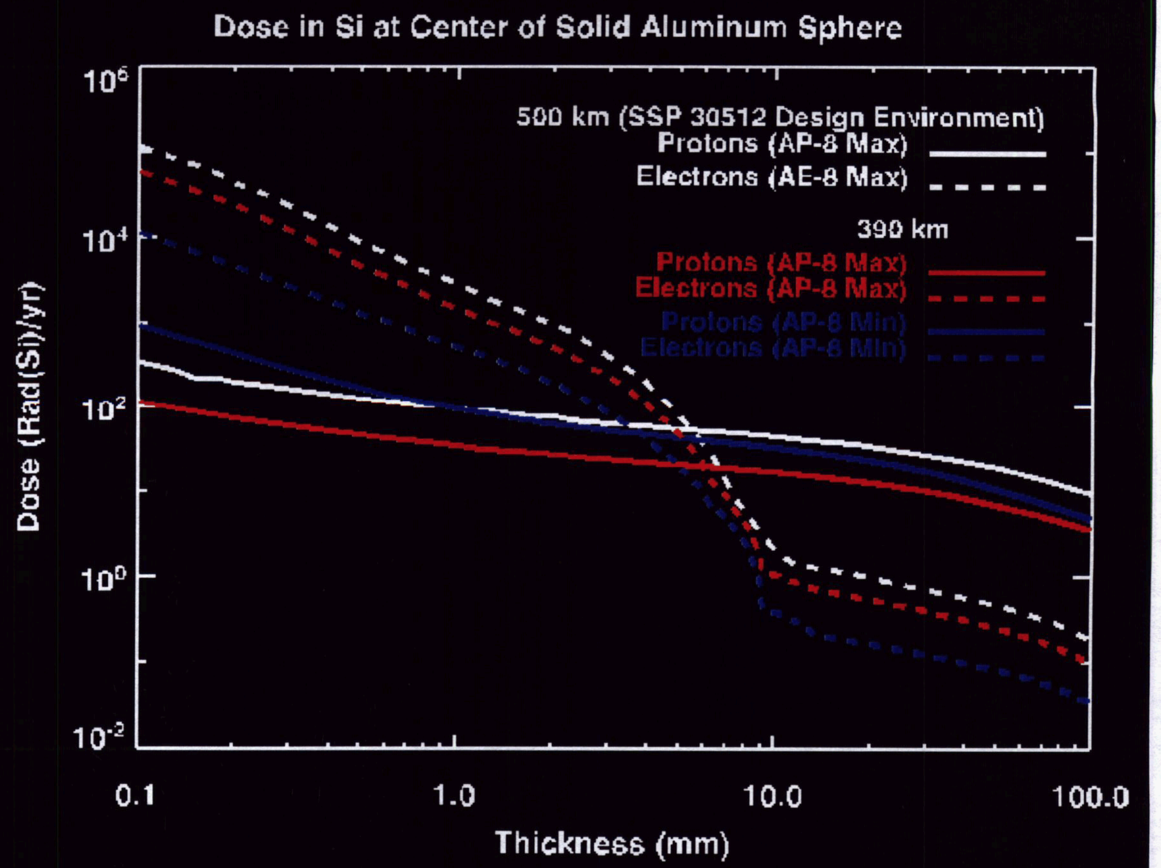
AE-8/AP-8, Mean Altitude

- **Quick analysis:**
  - **2 years (May 2000-May 2002) ISS radiation fluence**
  - **Mean 390 km altitude used to compute dose in material**

- **No attempt to determine dose variations due to changes in ISS altitude**

[Koontz et al., 2002]



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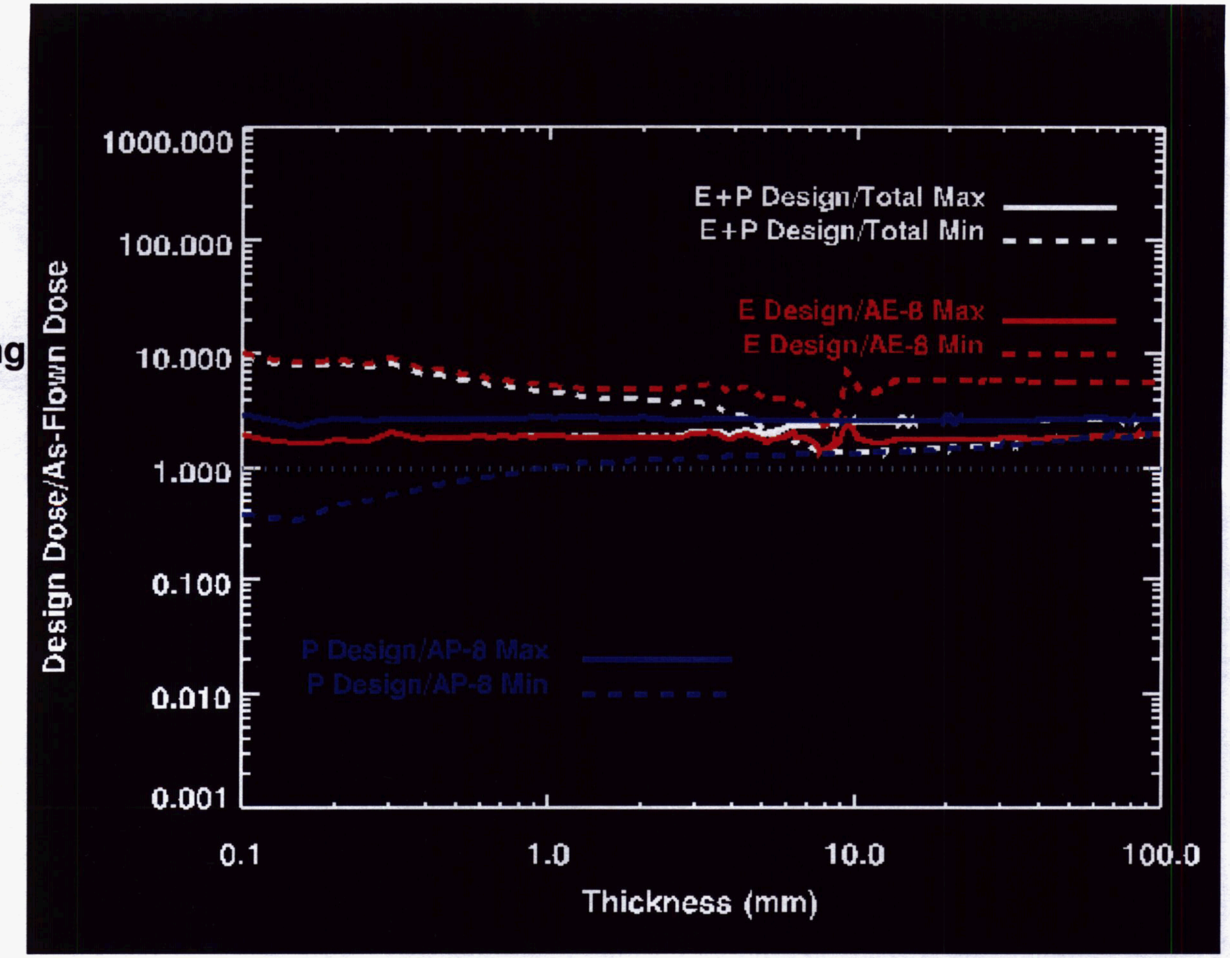
ISS Design, "As-Flown" Dose

- ISS cables insulated by 7 mil to 9 mil PTFE overwrap
  - (~0.2 mm per layer)
- 2 layers
  - 0.2 to 0.4 mm PTFE depending on whether cables are wrapped once or twice
- "As flown" dose ~10X design dose in 0.2 to 0.4 mm
- Suggests that 10 year estimated life of cables could be much longer



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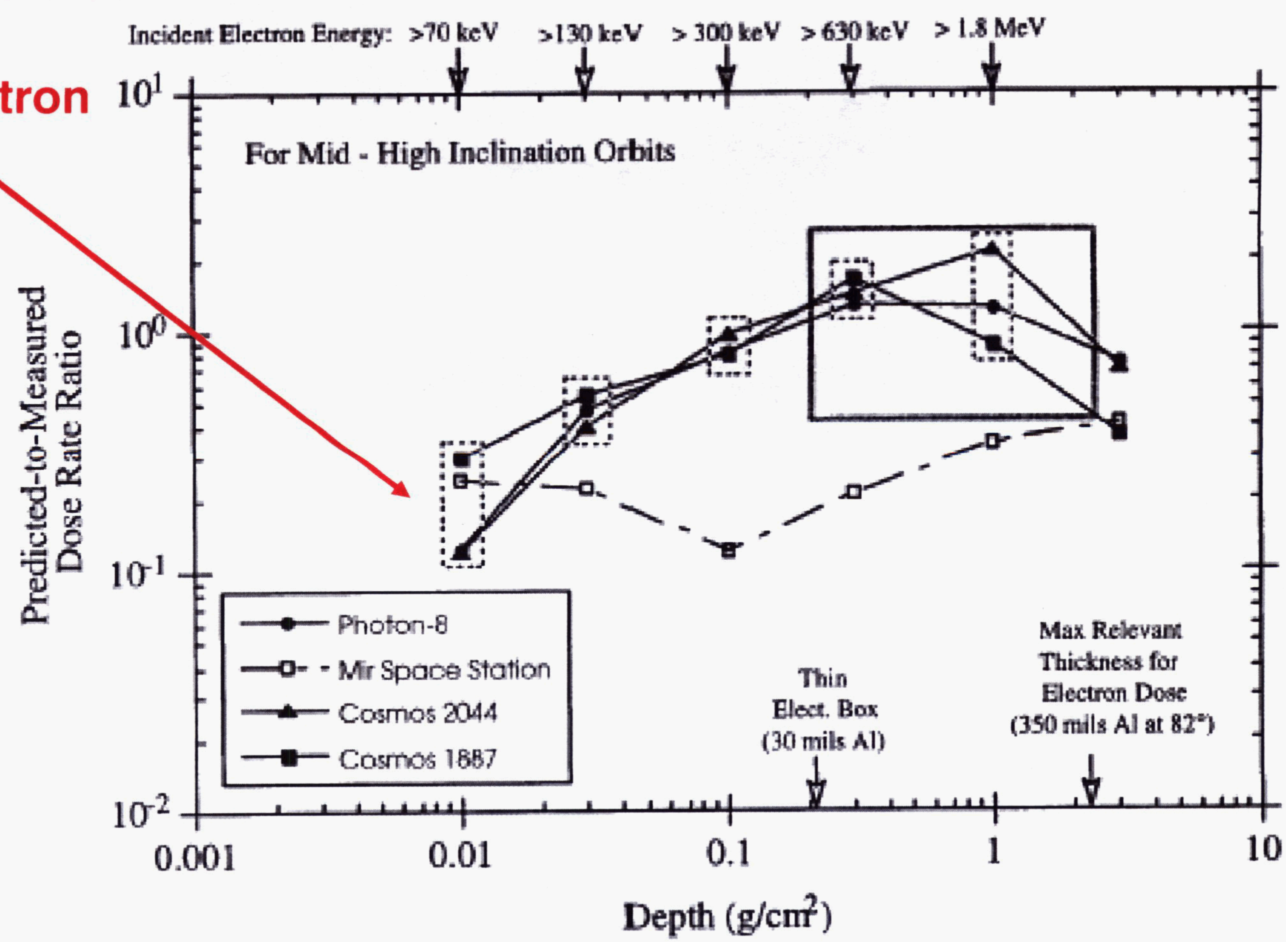
Predicted, Measured Dose

Need additional predicted vs measured dose information for electron energies <70 keV



- **T. W. Armstrong and B. L. Colborn, Trapped Radiation Model Uncertainties: Model-Data and Model-Model Comparisons, NASA/CR-2000-210071, NASA, Marshall Space Flight Center, Alabama 35812, March 2000, pp82.**

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ISS “As Flown” Orbit

- **ISS ephemeris data:**
  - ISS two line element sets provide orbit information

- **Satellite Tool Kit (STK) Merged Simplified General Perturbations (MSGP4) propagator used to compute orbit:**
  - *SGP4 propagators required to compute ephemeris using NORAD (USSPACECOM) TLE set format
  - Propagator model considers secular and periodic variations in orbit parameters due to Earth oblateness, solar and lunar gravitational effects, gravitational resonance effects and drag induced orbital decay

- **Generated ephemeris with MSGP4 propagator**
  - Period: 20 November 1998 to 1 June 2006
  - Time step: 60 seconds
  - Orbit file exported from STK as a geodetic longitude, latitude, and altitude text file for input to AE-8, AP-8

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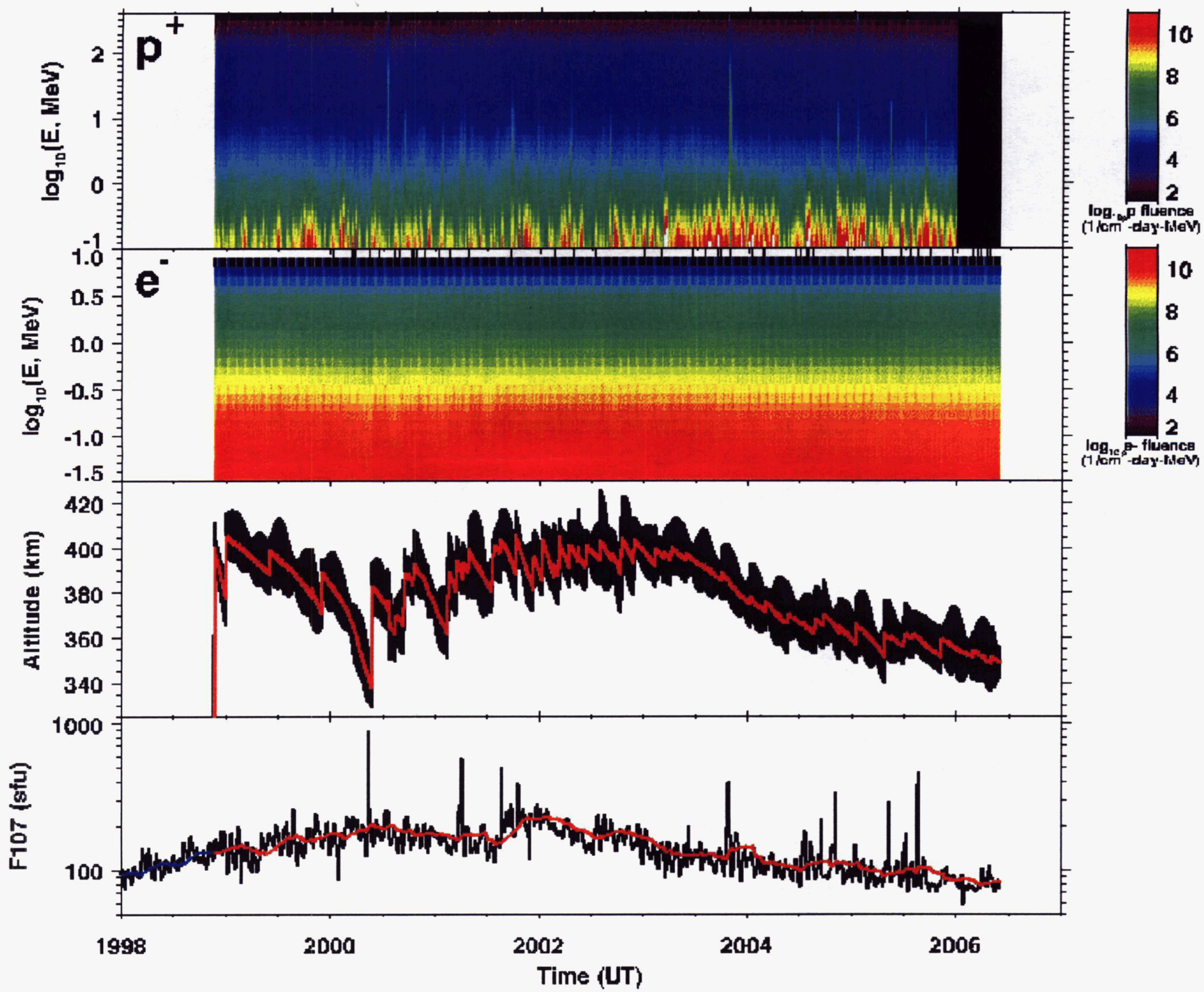
ISS "As flown"

AE-8/AP-8
Min



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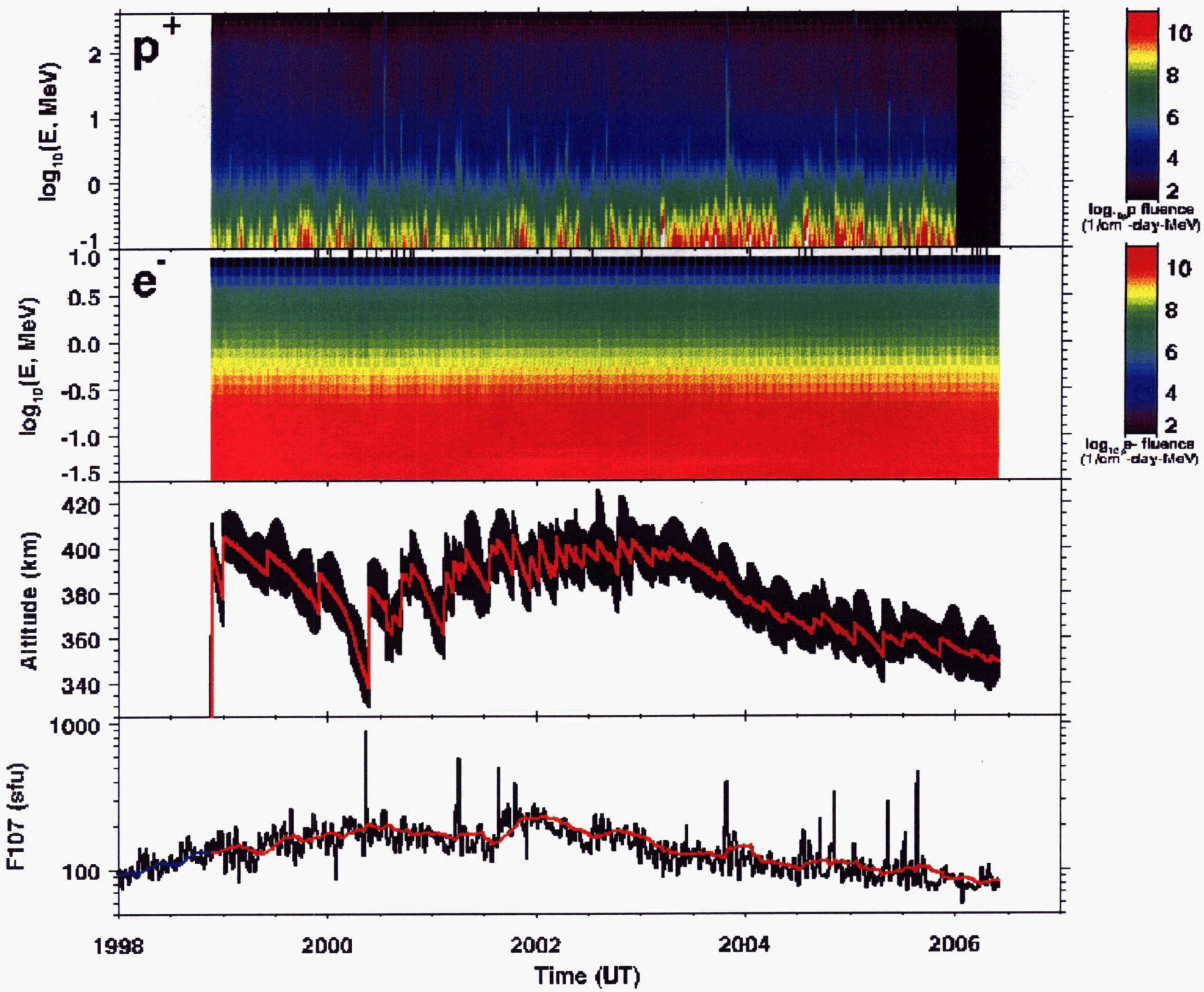
ISS "As flown"

AE-8/AP-8

Max



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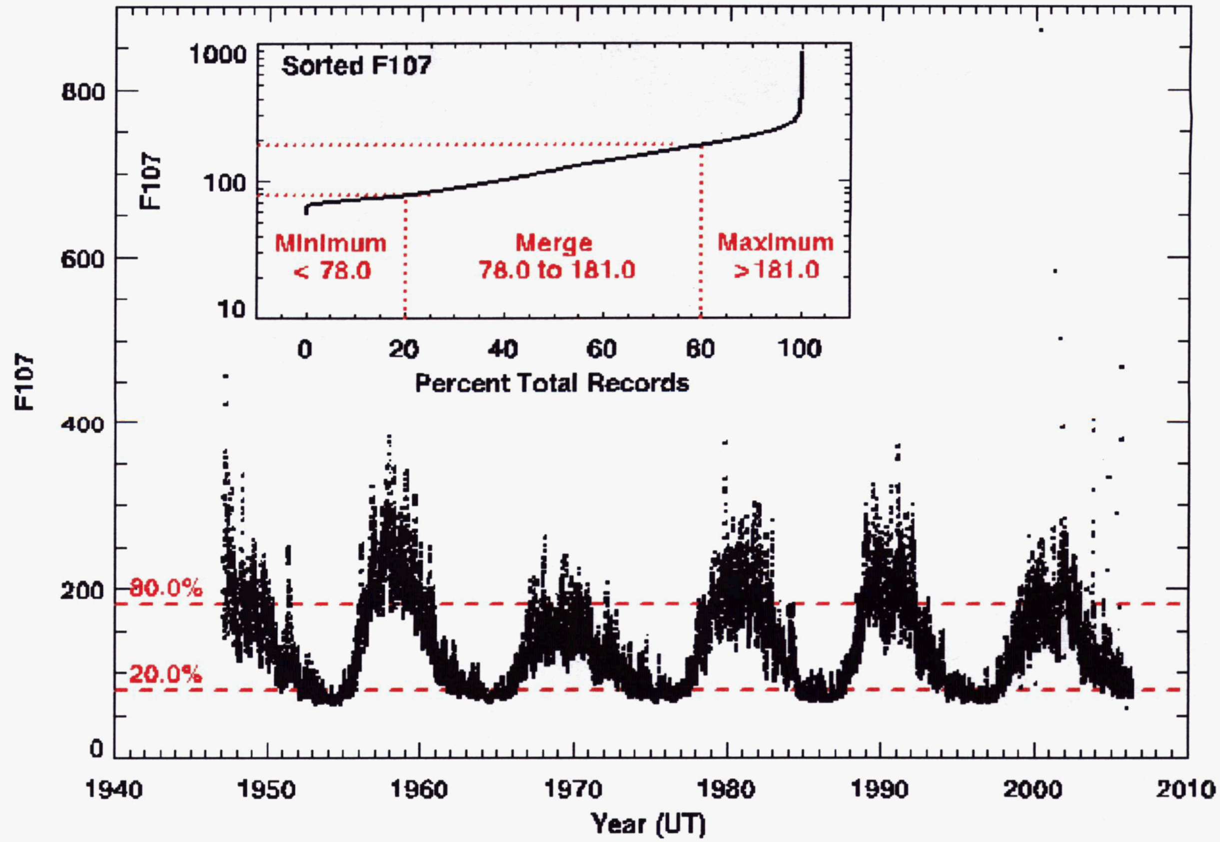
Objective Assignment of Solar Min or Max Models

- **AE/AP models for solar maximum, minimum only**
- **Strategies typically adopted for use include**
  - **Most severe model for conservative design use**
  - **7 yrs max, 5 yrs min for 11 year solar cycle**



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Solar Min/Max Weighting

- **Objective technique used for determining when to use solar minimum or solar maximum version of AE-8/AP-8 models [*Watts et al.*, 1996]**

- $\Phi = \alpha\Phi_{max} + (1-\alpha)\Phi_{min}$

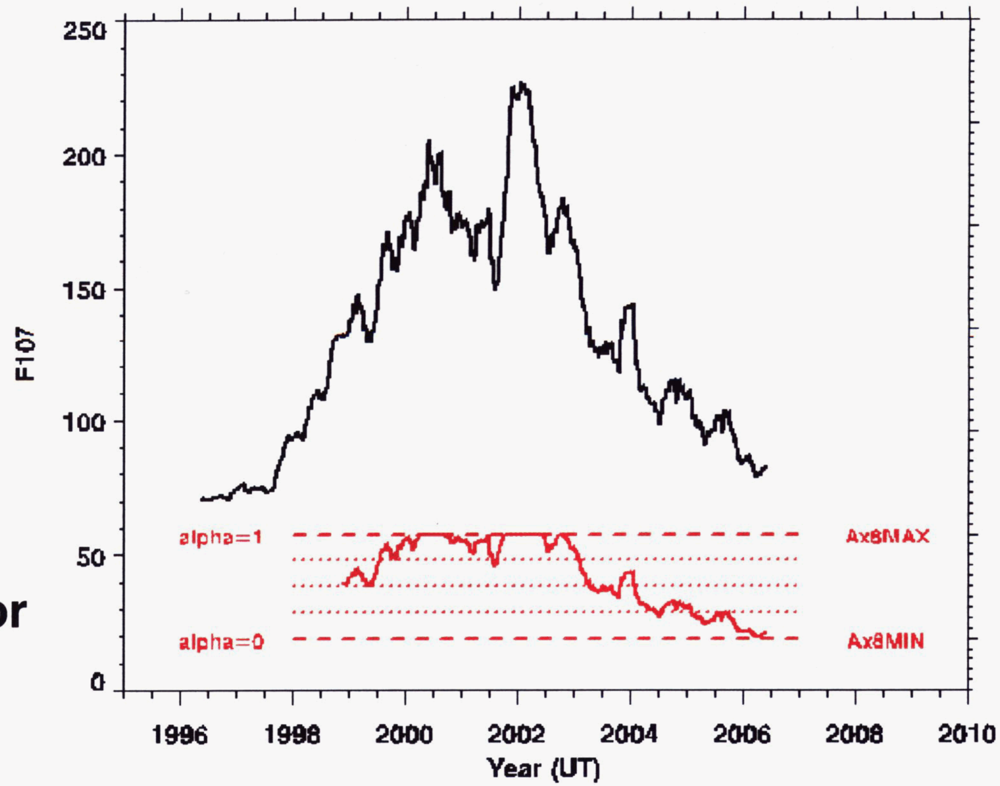
where Φ_{max} = **AE-8, AP-8 max**

Φ_{min} = **AE-8, AP-8 min**

α = **F107 weighting factor**

= **0 for solar min**

= **1 for solar max**



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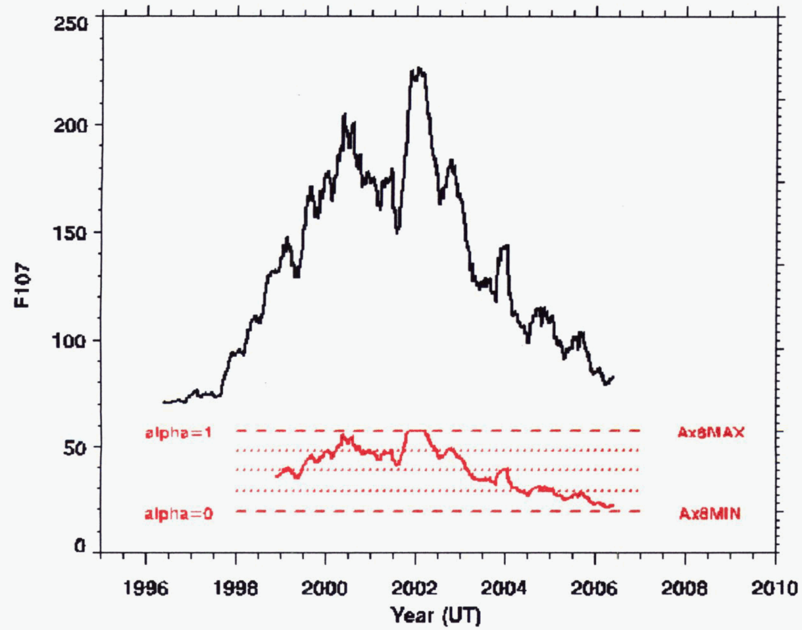
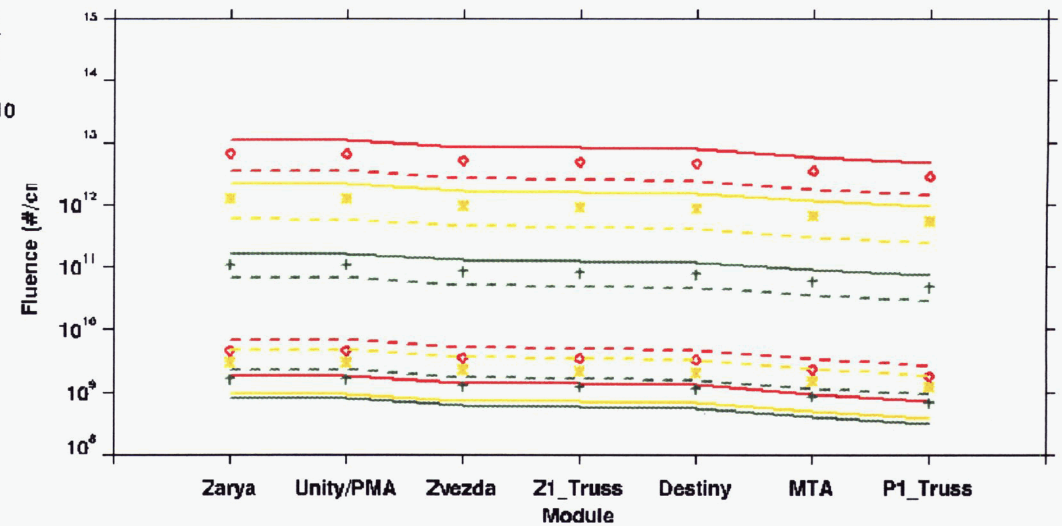
10%/90%





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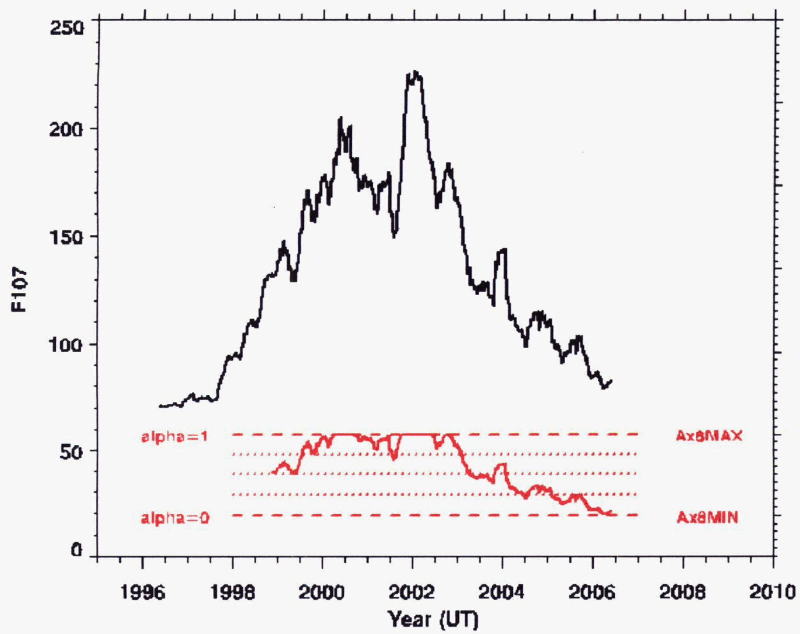
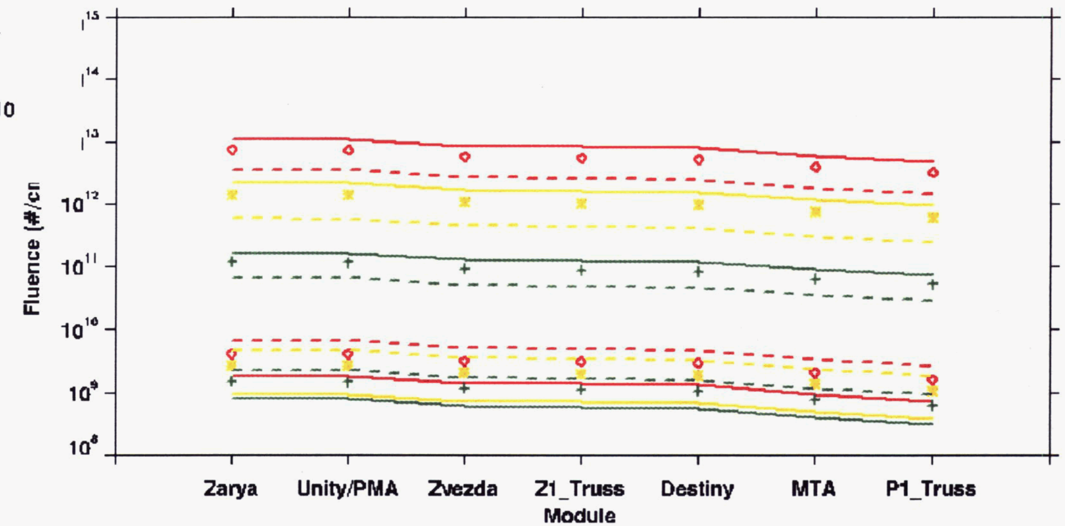
20%/80%





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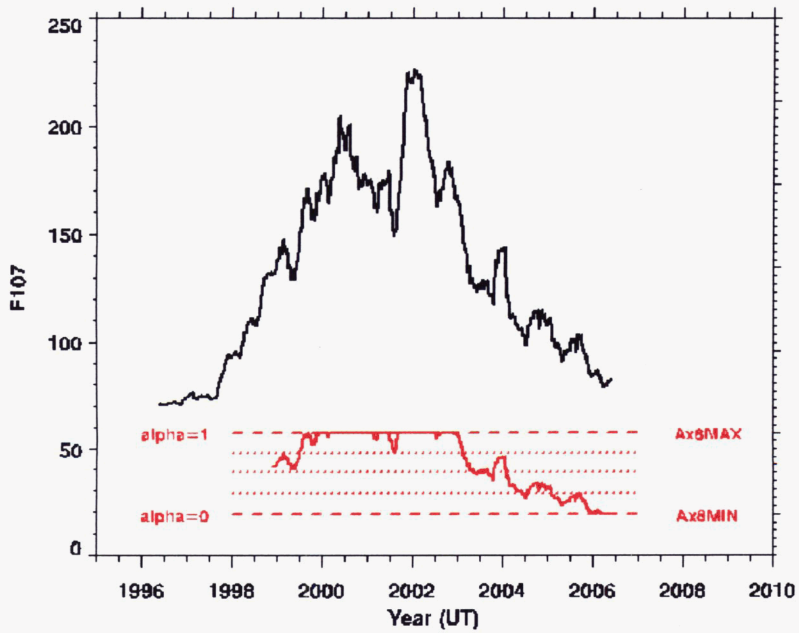
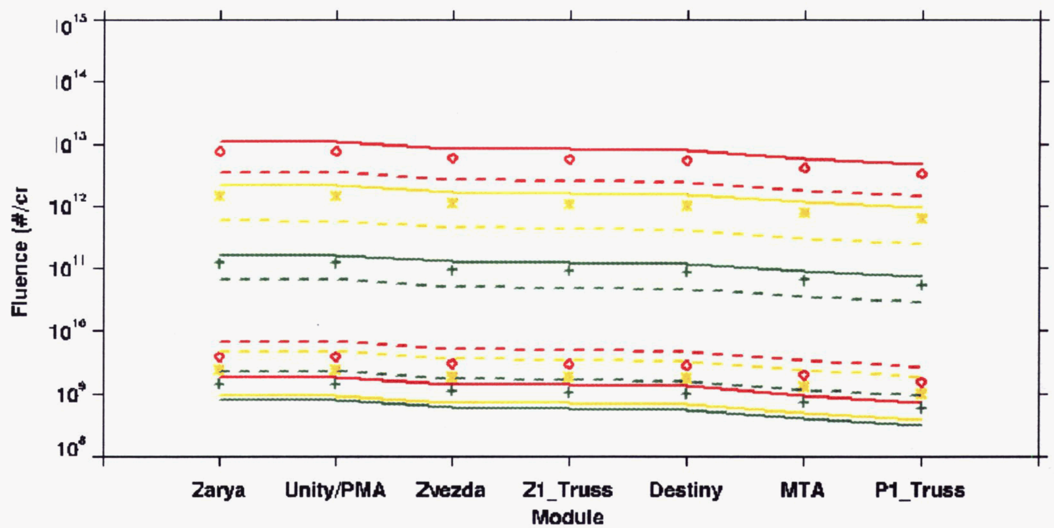
25%/75%





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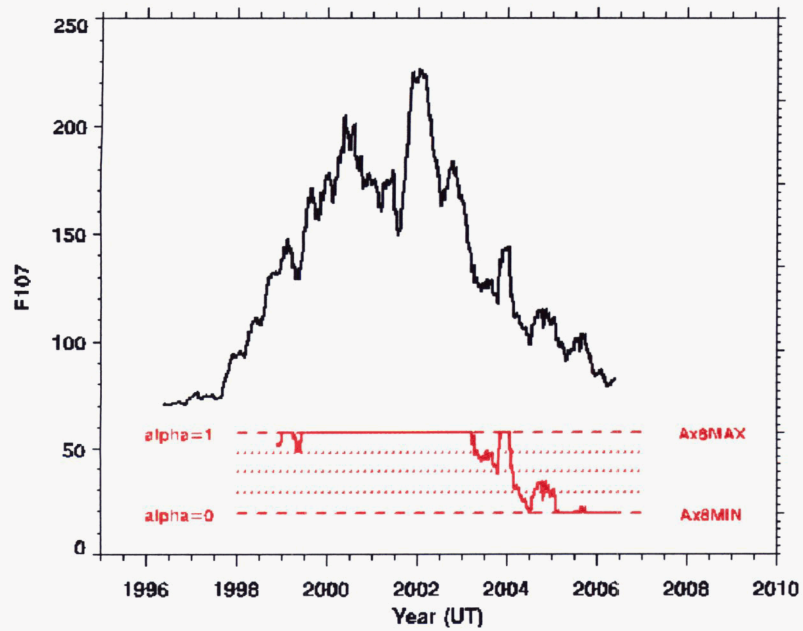
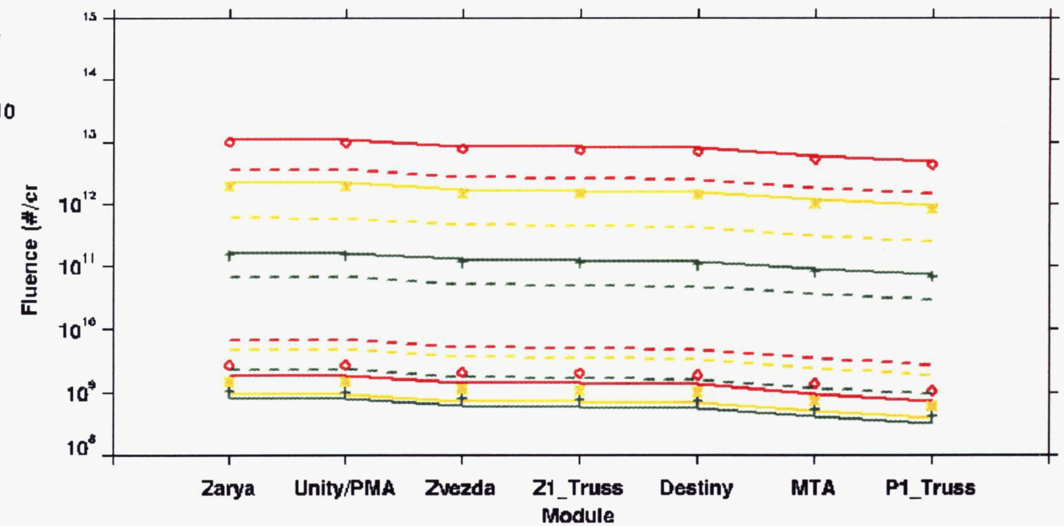
40%/60%





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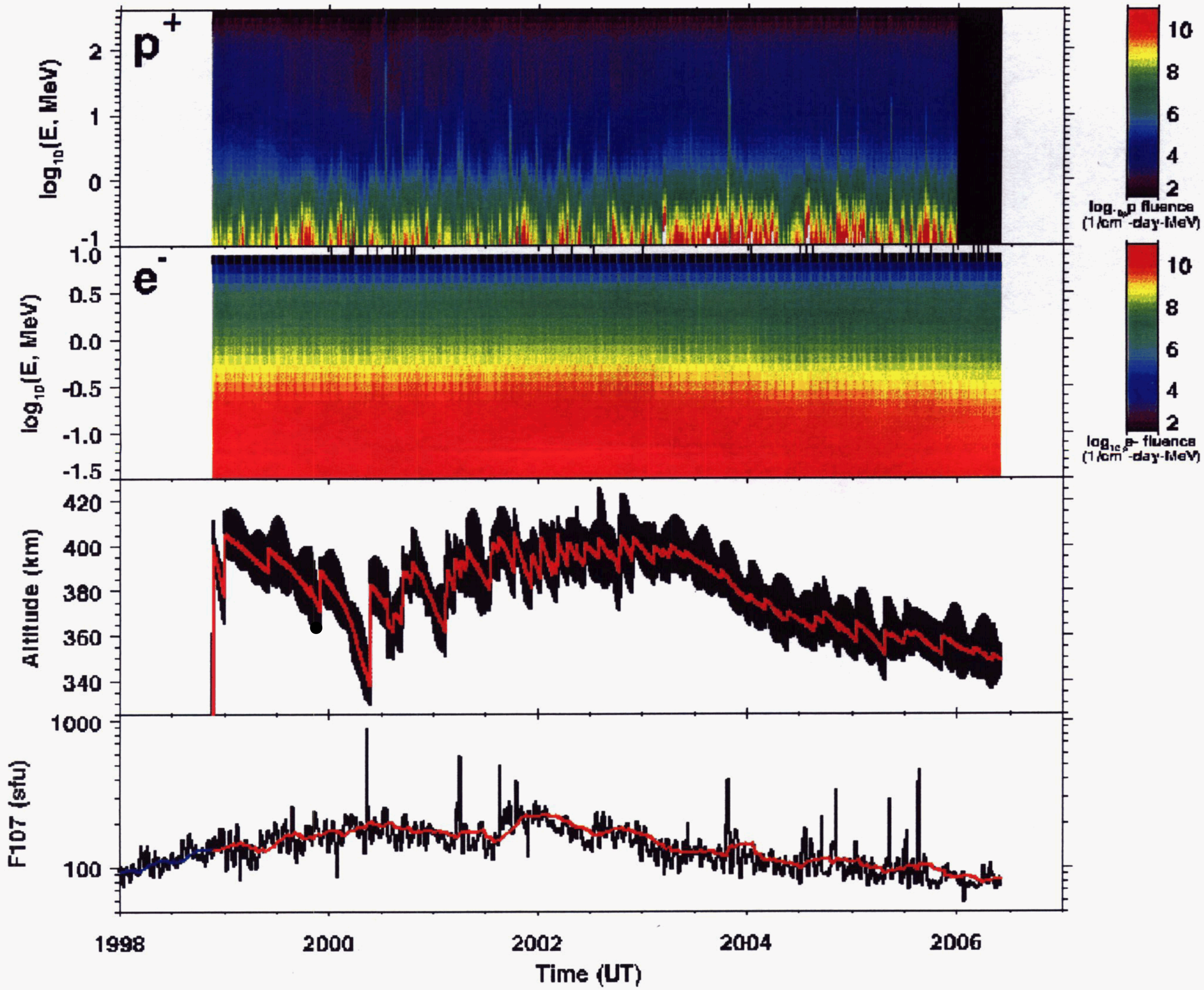
ISS “As flown”

AE-8/AP-8

Min

Max



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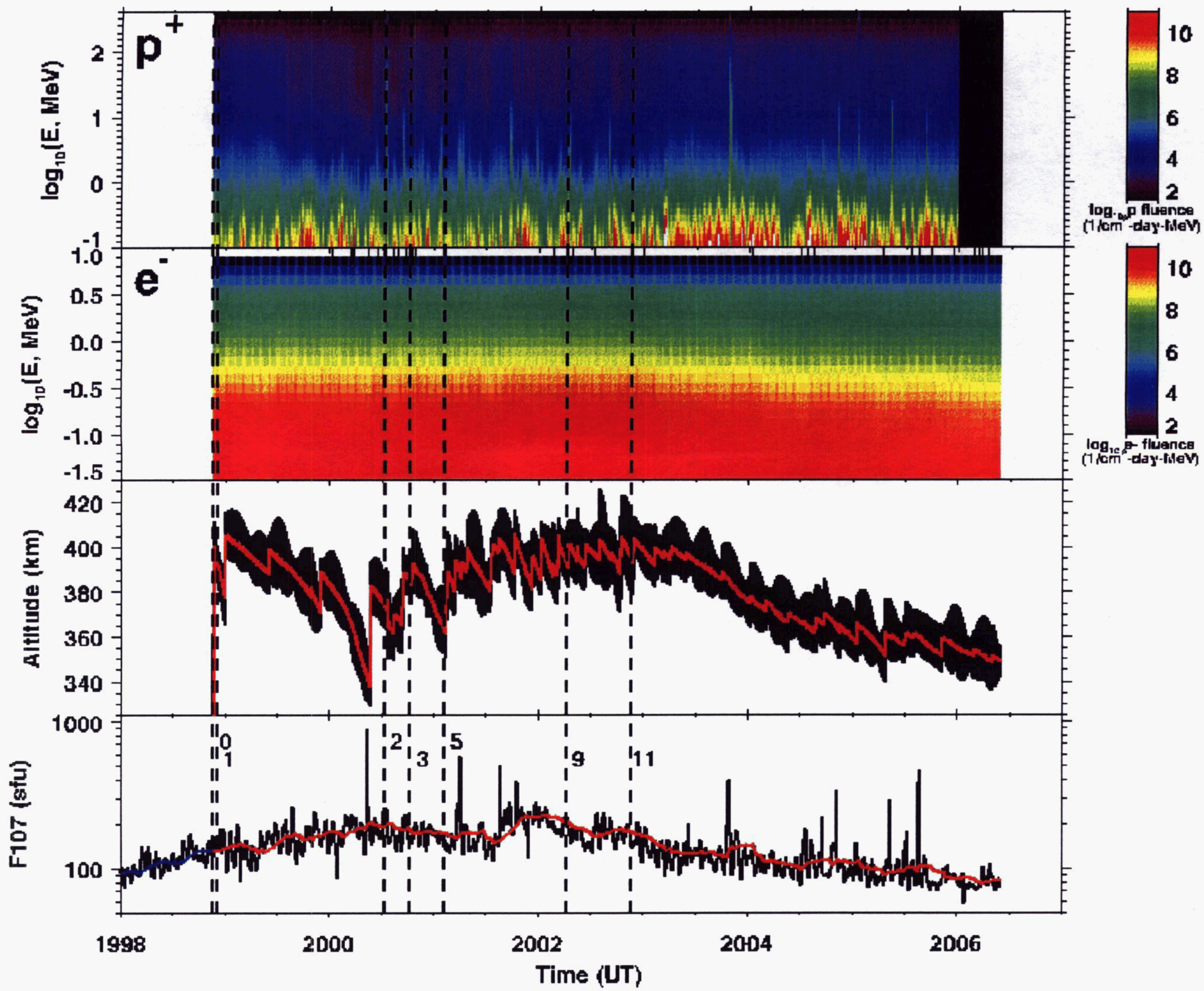
ISS "As flown"

AE-8/AP-8

Min

Max

Modules



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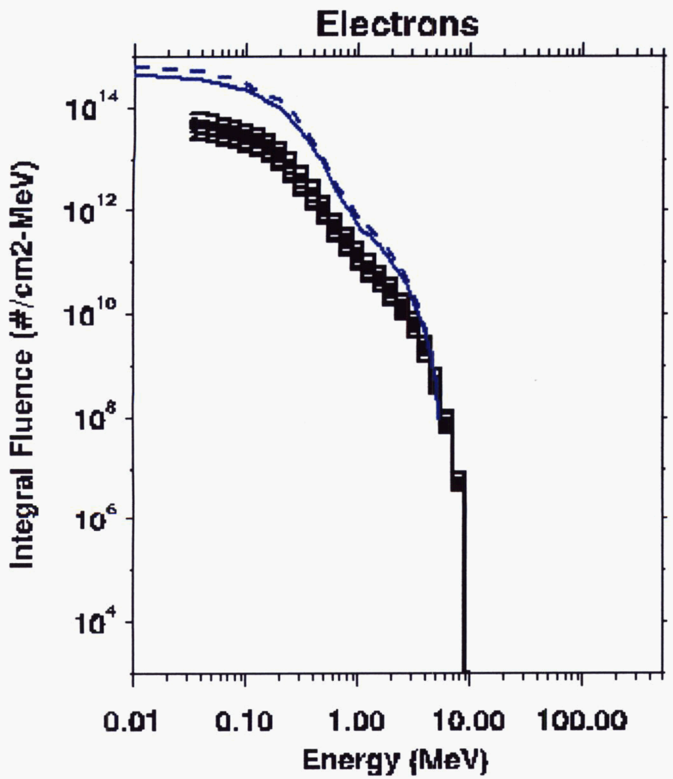
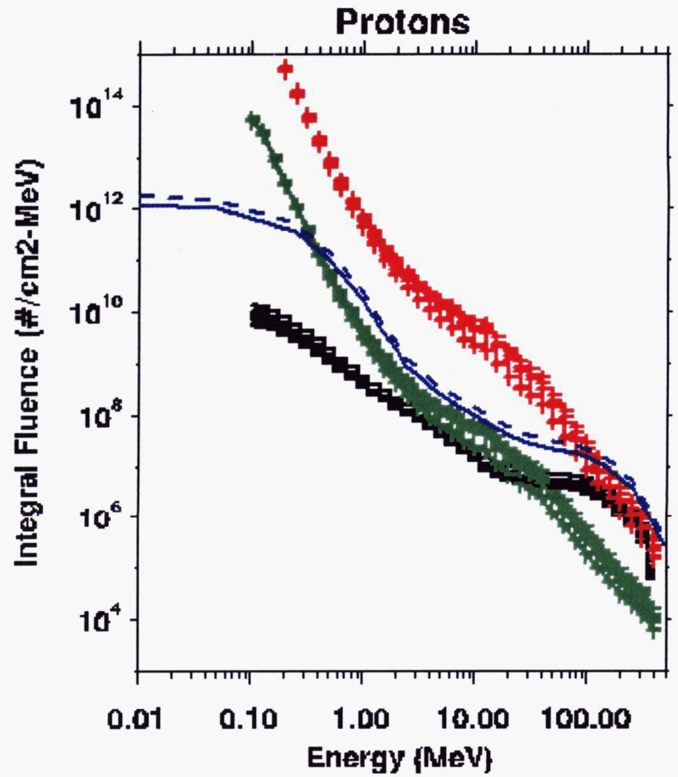
“As-flown” Fluences





- Trapped electrons
- 30512 Design Environment

- Trapped protons
- GOES solar protons (GEO)
- GOES solar protons (LEO)
- 30512 Design Environment

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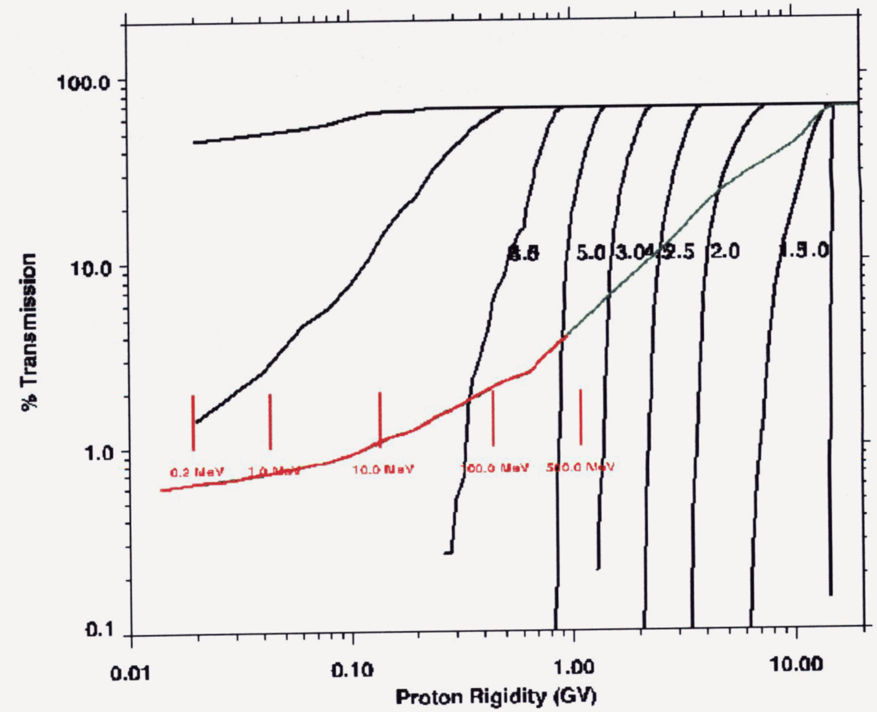
Solar Protons

Event	>30 MeV fluence (#/cm2)
2000/07/12	4.3×10^9
2000/08/00	3.2×10^9
2001/09/24	1.2×10^9
2001/11/04	3.4×10^9
2003/10/28	3.4×10^9
2005/01/15	1.0×10^9
Total	16.5×10^9

Sources: Reedy, 2006



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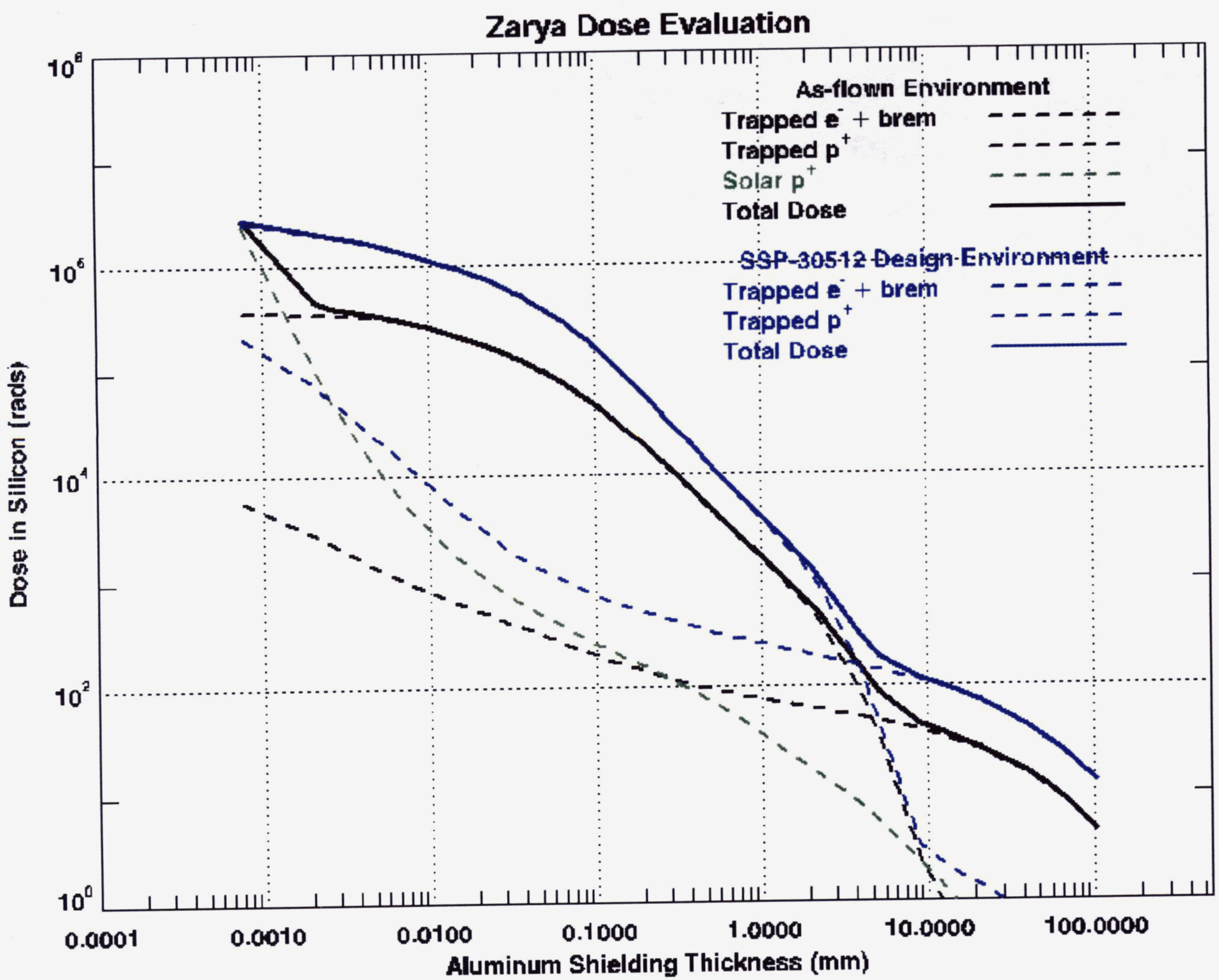
"As-flown" Dose



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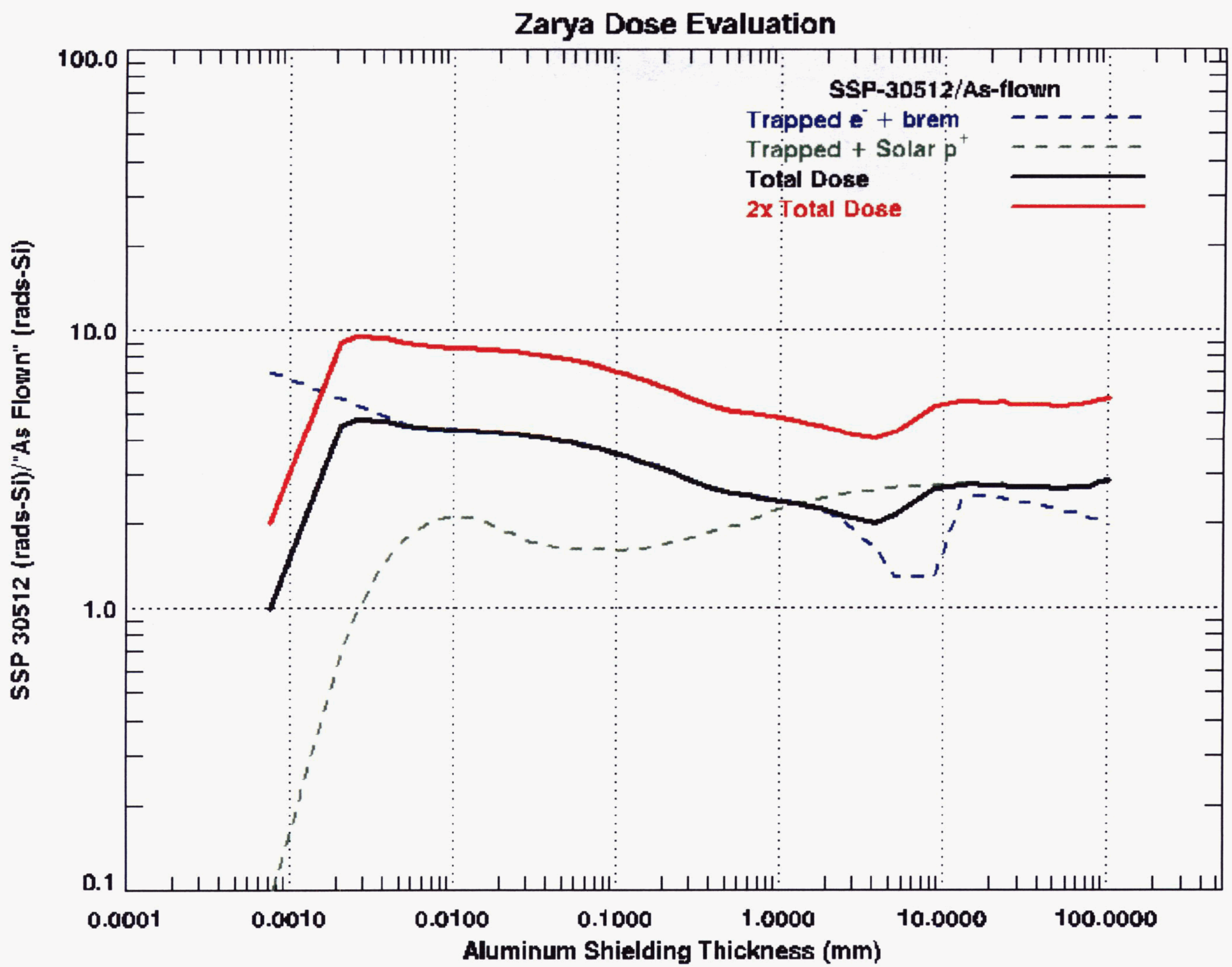
“As-flown” Dose Ratios



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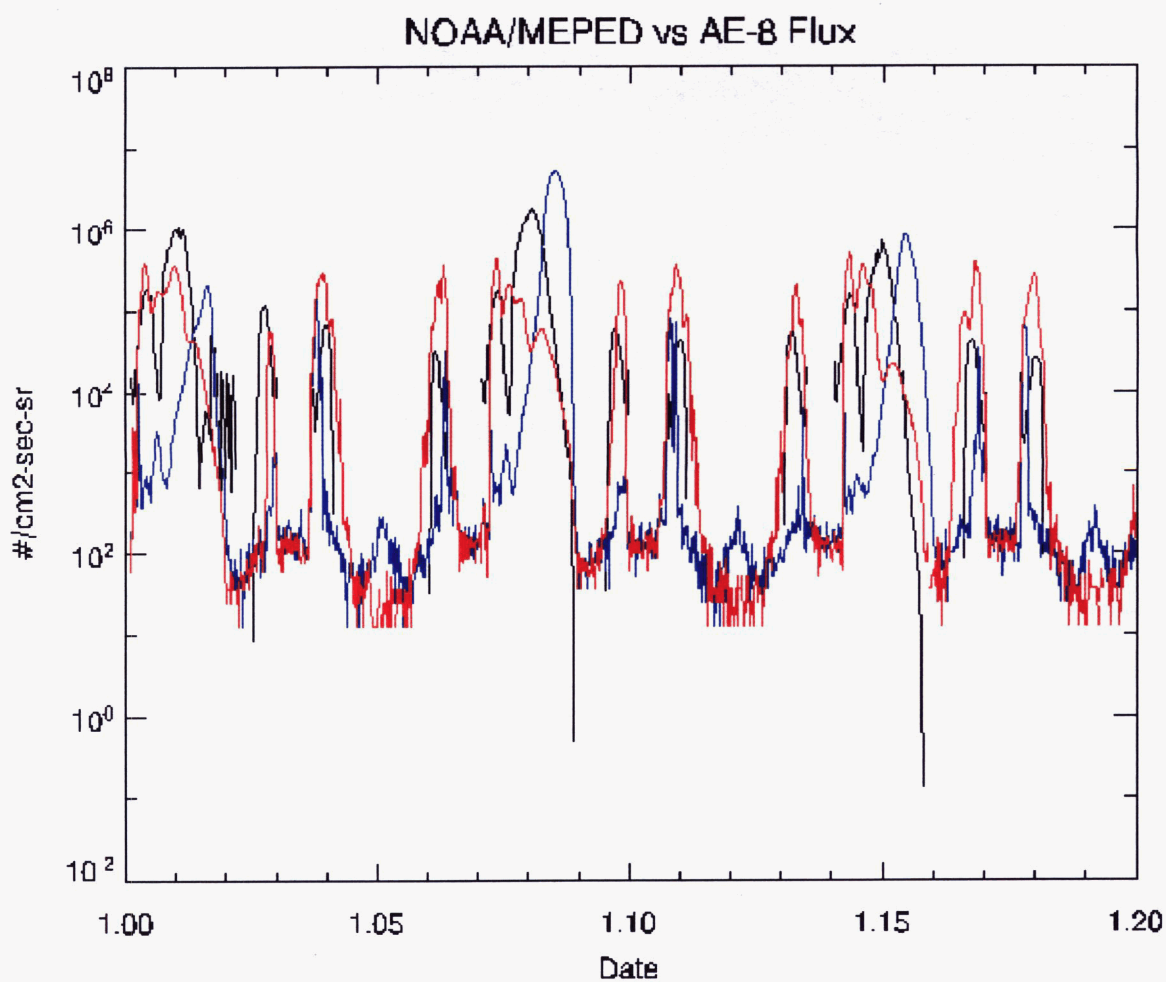
NOAA MEPED Data vs AE-8 Model

- NOAA 0 deg
- NOAA 90 deg
- AE-8



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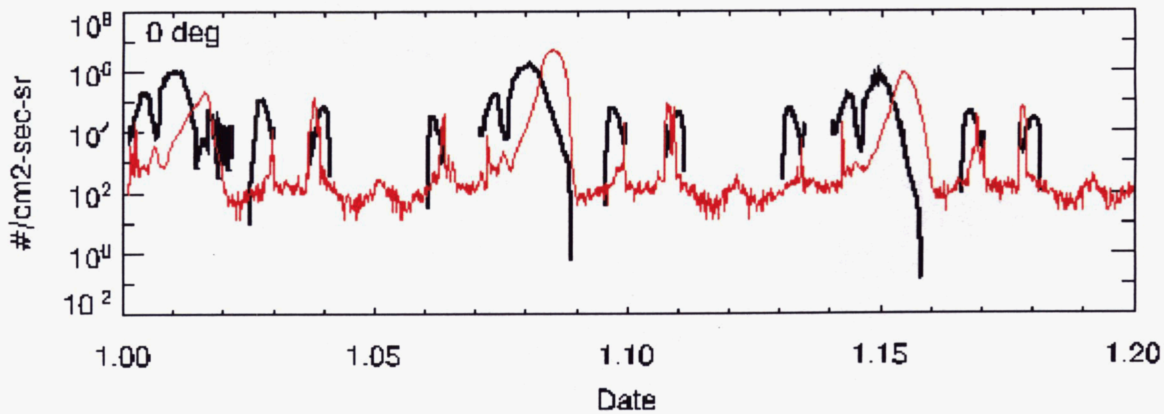
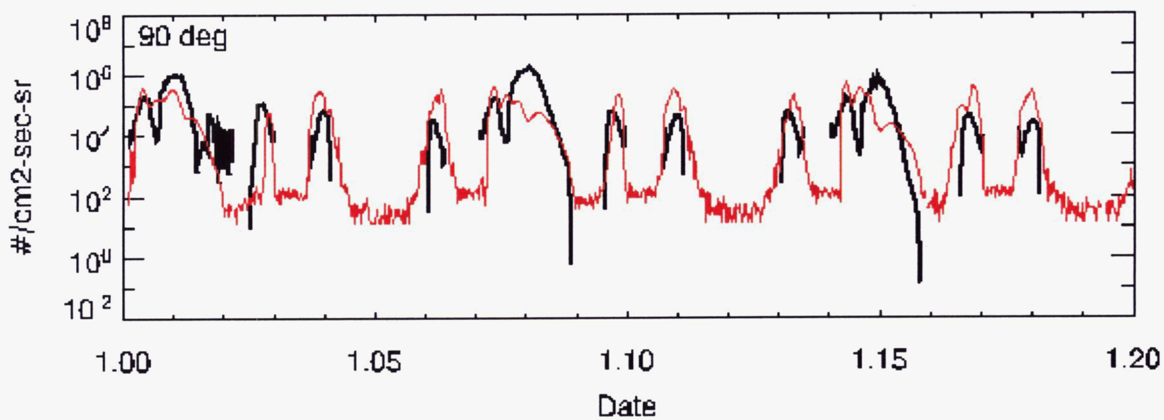
NOAA Data vs AE-8

0 deg



90deg



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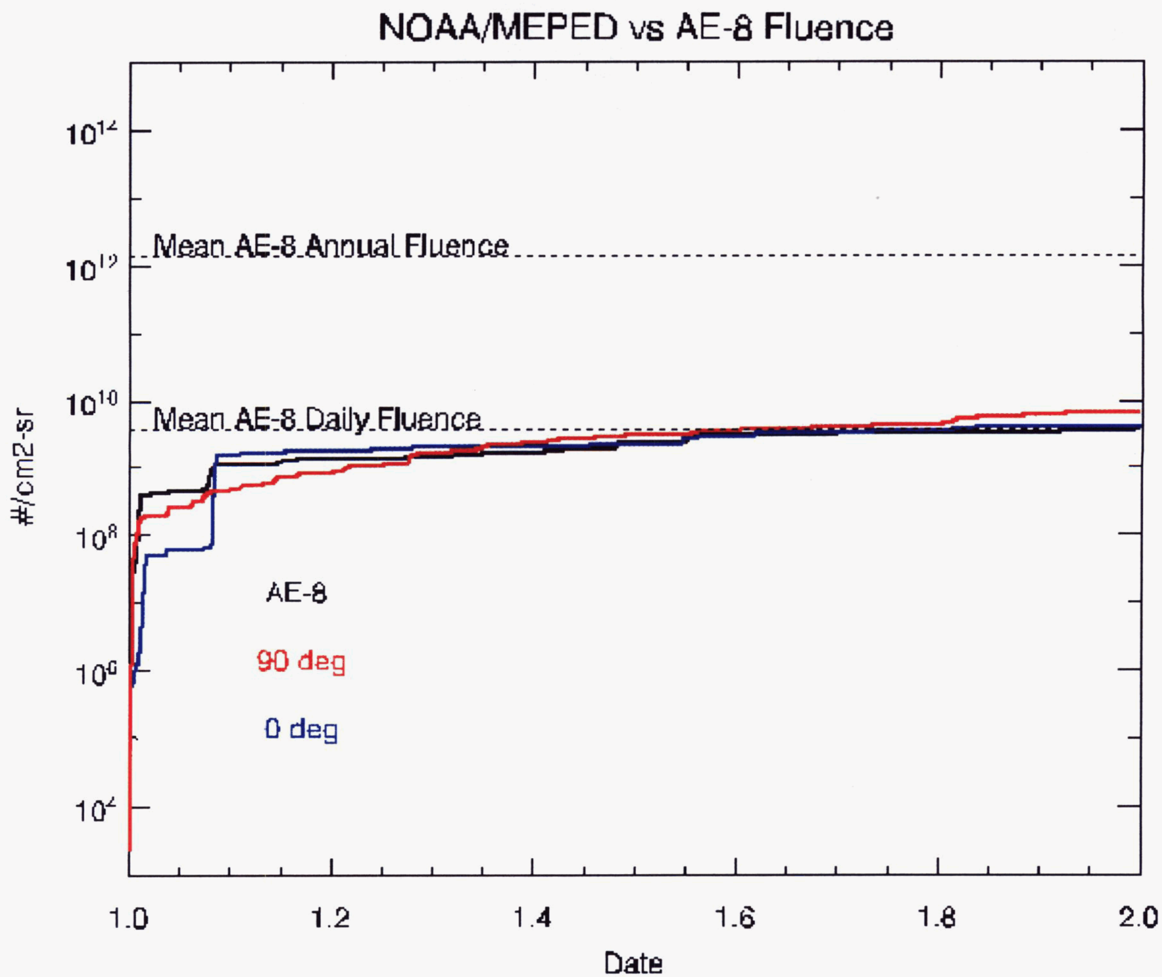
Daily Fluence Example



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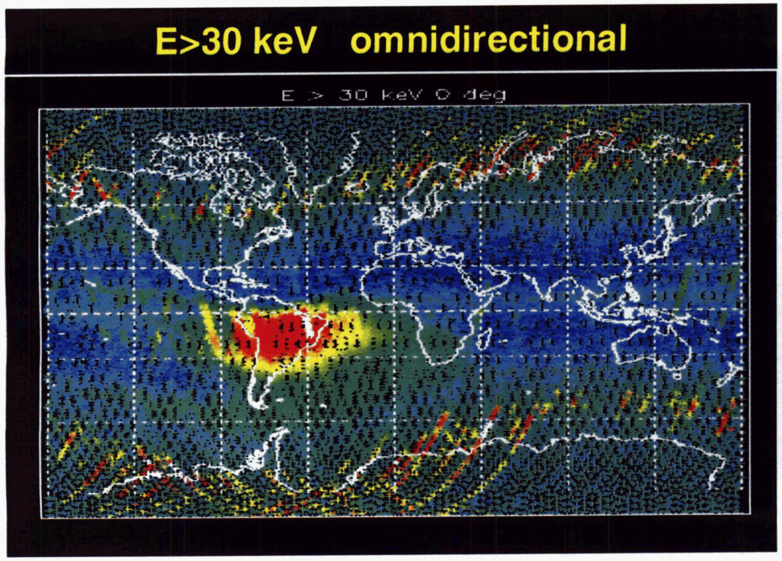
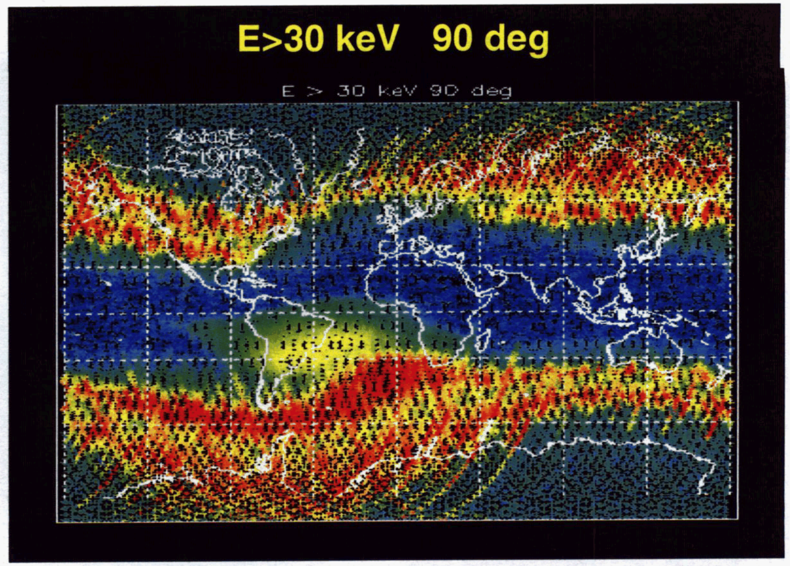
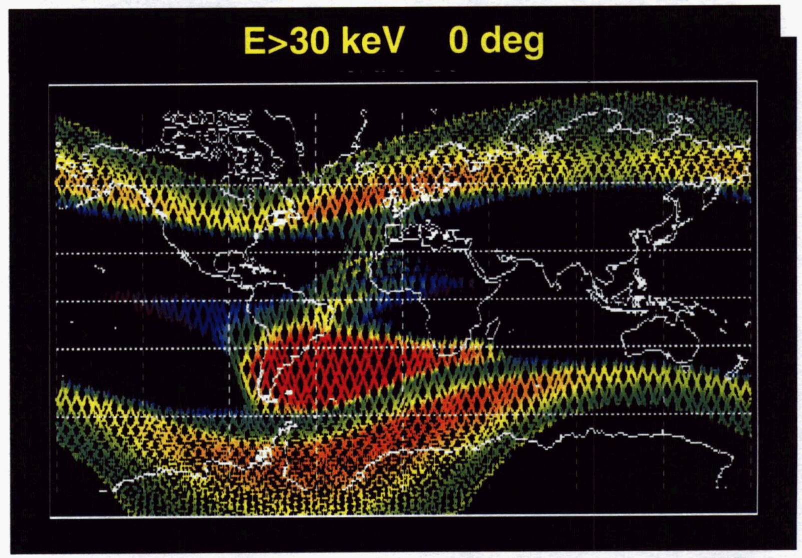
NOAA Electrons







AE-8 omnidirectional flux

NOAA electrons measured in two orthogonal directions

-- 0 deg in zenith on zenith-nadir line

--90 deg perpendicular to velocity

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Summary

- SSP 30512 design environment for dose over estimates actual flight dose
  - SSP 30512/as flown reference environment
    - ~2x to 4x for 0.01 mm to 100 mm
    - ~2x at minimum between 2 to 8 mm over qualification
  - 2x SSP 30512/as flown reference environment
    - ~4x to 8x for 0.01 mm to 100 mm
    - ~4x at minimum between 2 to 8 mm over qualification

- Dose includes
  - Trapped electrons, bremstrahlung x-rays
  - Trapped protons, solar protons

- Materials originally qualified for ~10 to 15 years anticipated to be acceptable for use for periods of up
  - 20 to 30 years based on SSP-30512
  - 40 to 60 years based on 2x SSP-30512

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